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**Iyer et al.**

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(54) **SYSTEMS, APPARATUS, AND METHODS FOR PURGING A SUBSTRATE CARRIER AT A FACTORY INTERFACE**

(58) **Field of Classification Search**  
CPC ..... H01L 21/67383; H01L 21/67772; H01L 21/67017; H01L 21/67389  
See application file for complete search history.

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(56) **References Cited**

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U.S. PATENT DOCUMENTS

6,899,145 B2 5/2005 Aggarwal  
7,726,353 B2 6/2010 Okabe  
2003/0031537 A1 2/2003 Tokunaga  
2006/0272169 A1 12/2006 Miyajima  
2009/0035099 A1 2/2009 Okabe et al.

(Continued)

FOREIGN PATENT DOCUMENTS

TW 2007325256 9/2007

OTHER PUBLICATIONS

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International Preliminary Report on Patentability of International Application No. PCT/US2015/057005 dated May 4, 2017.

(Continued)

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(21) Appl. No.: **14/920,785**

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(22) Filed: **Oct. 22, 2015**

(65) **Prior Publication Data**

(57) **ABSTRACT**

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Embodiments of the present invention provide systems, apparatus, and methods for purging a substrate carrier. Embodiments include a frame configured to sit proximate to a load port door without interfering with operation of a factory interface or equipment front end module robot; one or more inter-substrate nozzle arrays supported by the frame and configured to spray gas into a substrate carrier; and one or more curtain nozzle arrays supported by the frame and configured to spray gas across an opening of the substrate carrier. Numerous additional aspects are disclosed.

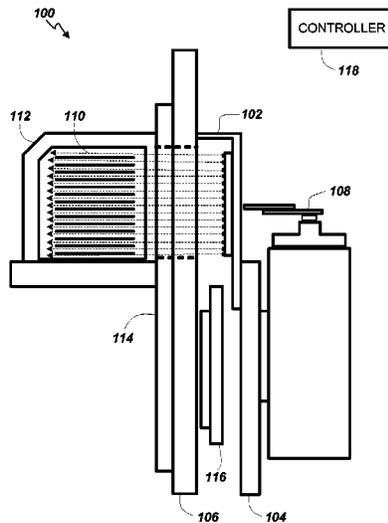
**Related U.S. Application Data**

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(51) **Int. Cl.**  
**H01L 21/673** (2006.01)  
**H01L 21/677** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **H01L 21/67383** (2013.01)

**13 Claims, 8 Drawing Sheets**



(56)

**References Cited**

U.S. PATENT DOCUMENTS

2009/0035100	A1	2/2009	Okabe et al.
2009/0169342	A1	7/2009	Yoshimura et al.
2012/0060972	A1	3/2012	Okabe
2013/0042945	A1	2/2013	Emoto et al.
2014/0157722	A1	6/2014	Iwamoto
2015/0040950	A1	2/2015	Kaise et al.
2015/0214078	A1	7/2015	Iwamoto et al.

OTHER PUBLICATIONS

International Search Report and Written Opinion of International Application No. PCT/US2015/057005 dated Jan. 20, 2016.  
Taiwan Search Report of Taiwan Application No. 104134921 dated Dec. 6, 2018.

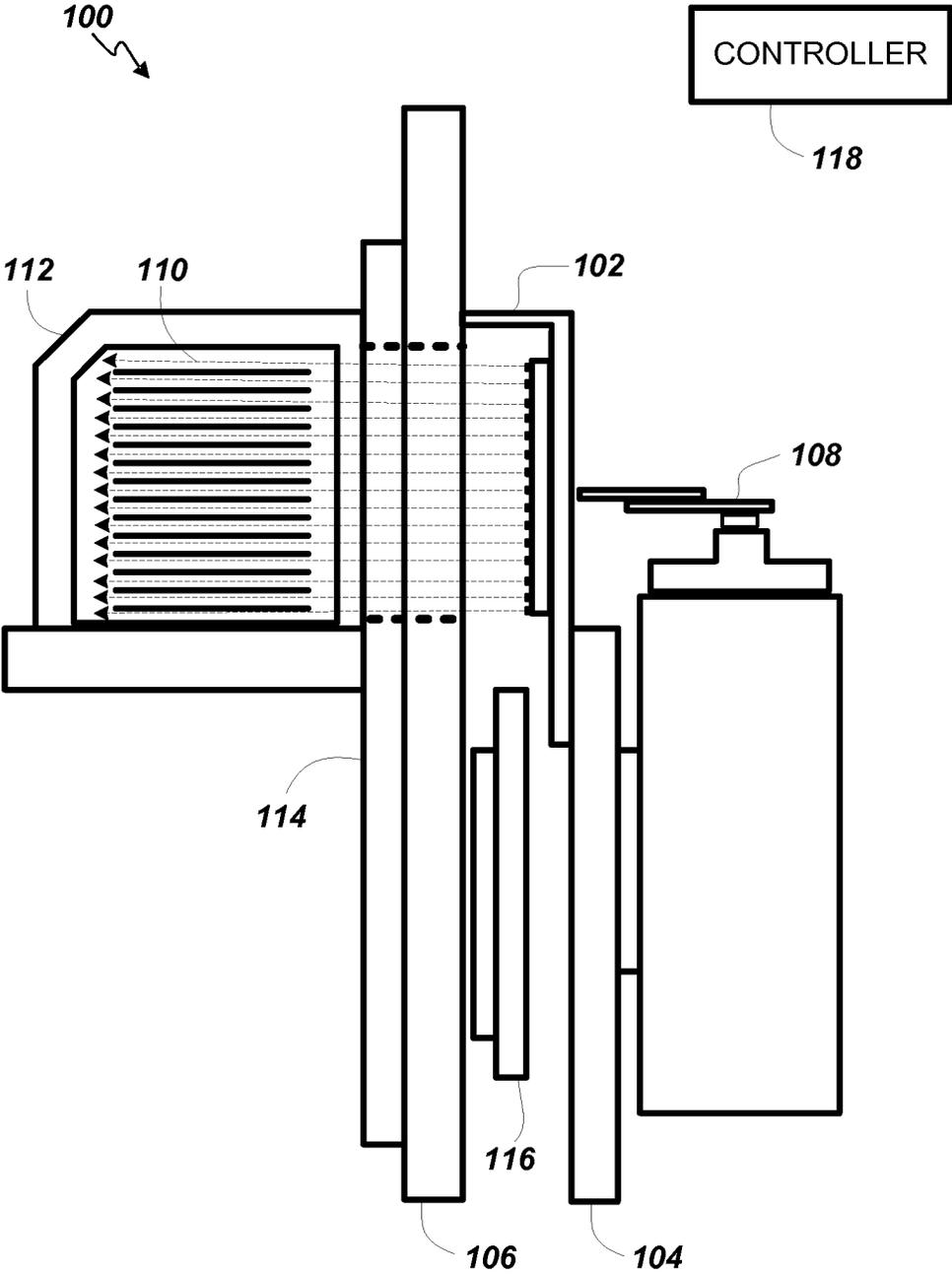


FIG. 1

200 ↘

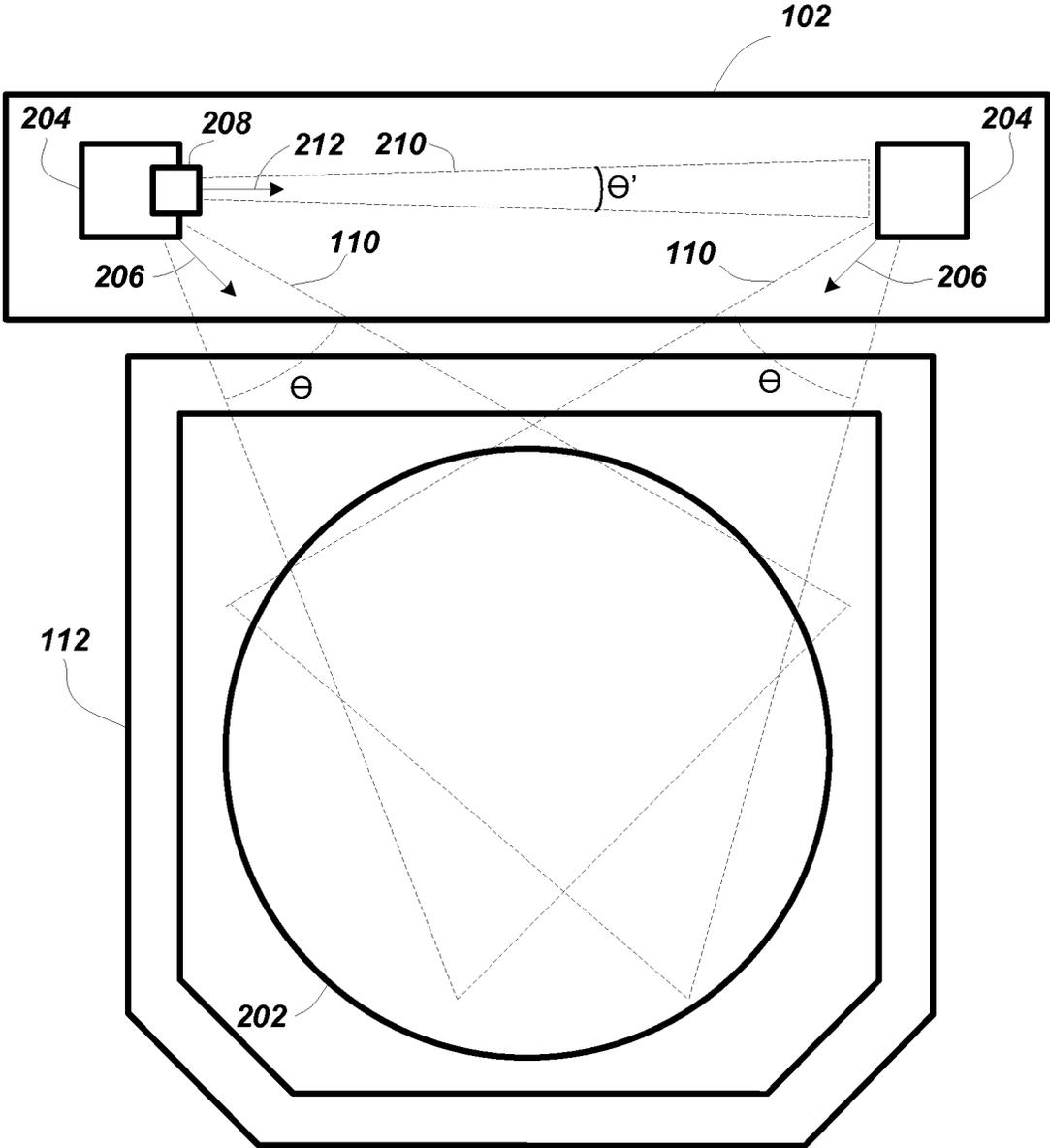


FIG. 2

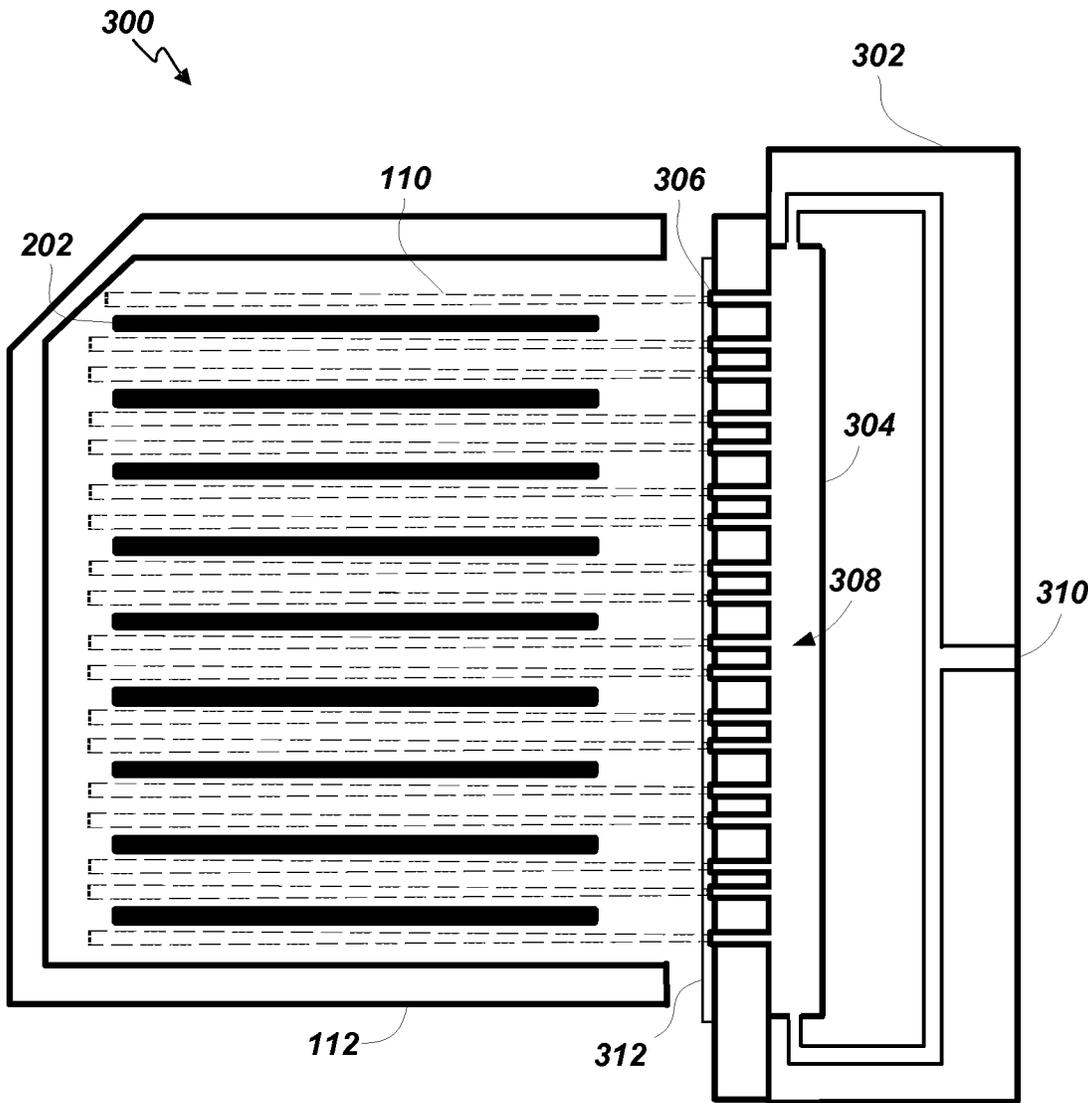


FIG. 3

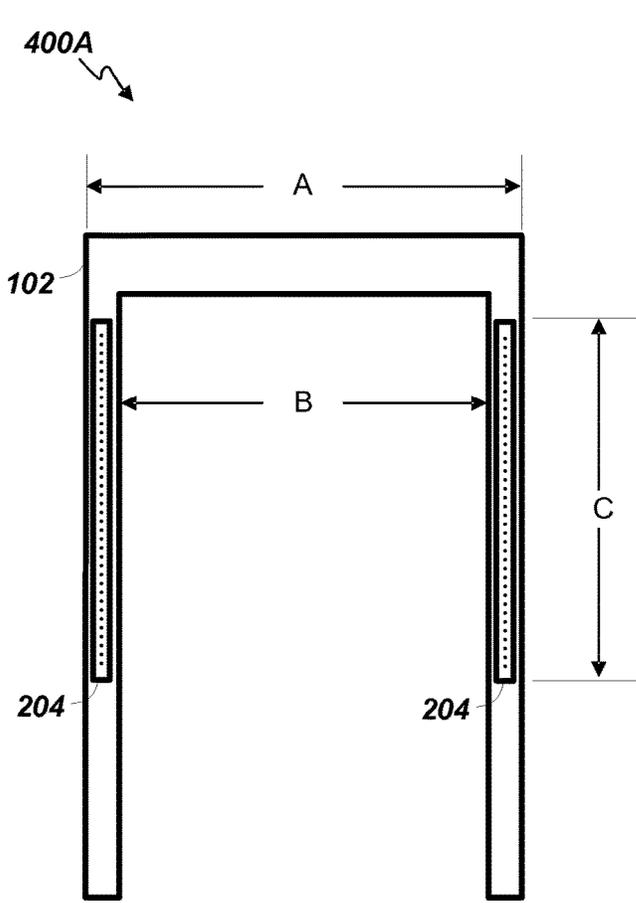


FIG. 4A

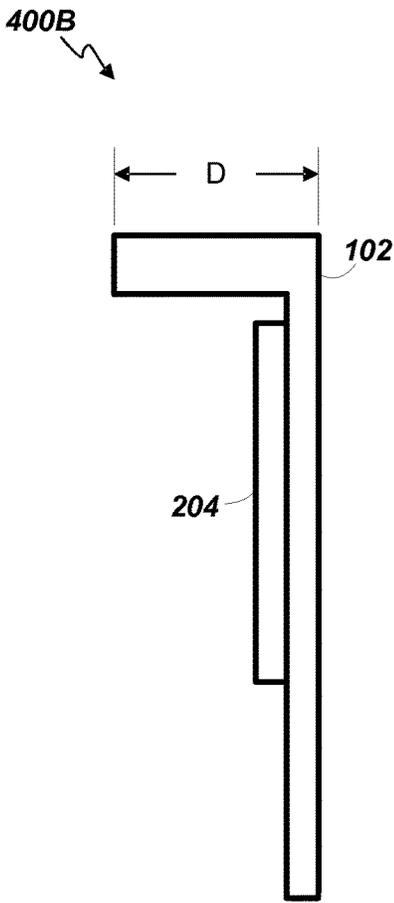


FIG. 4B

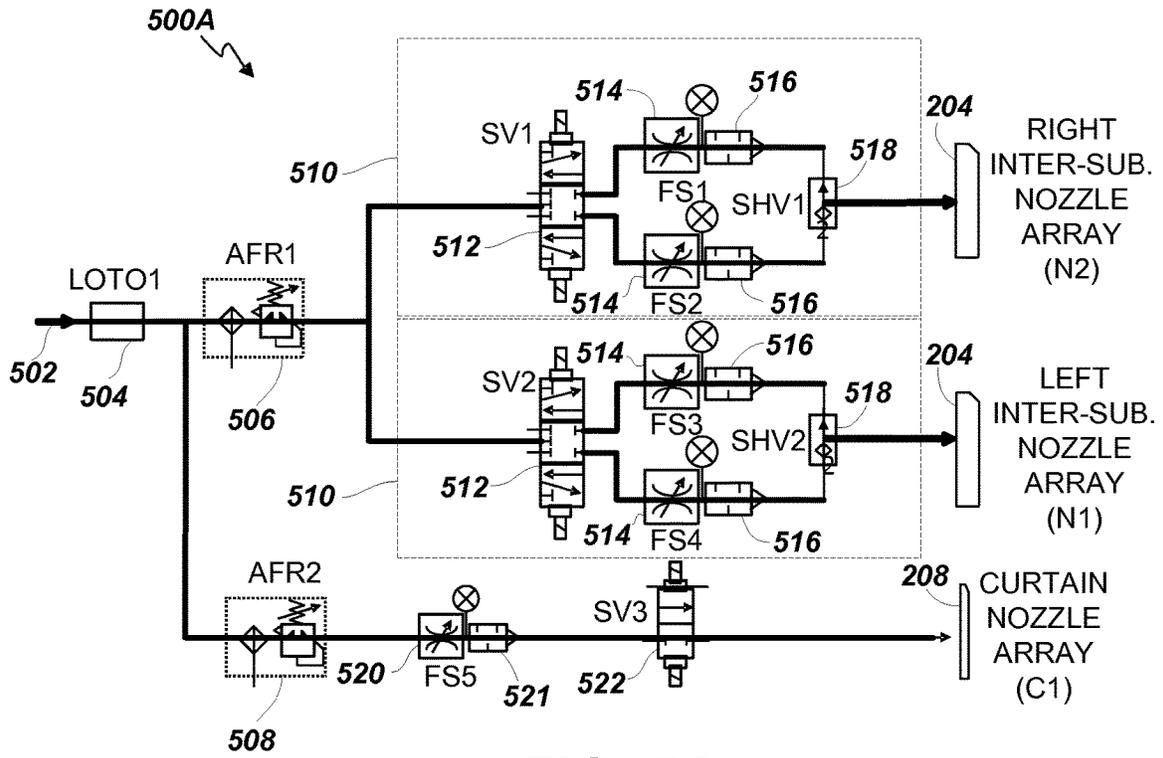


FIG. 5A

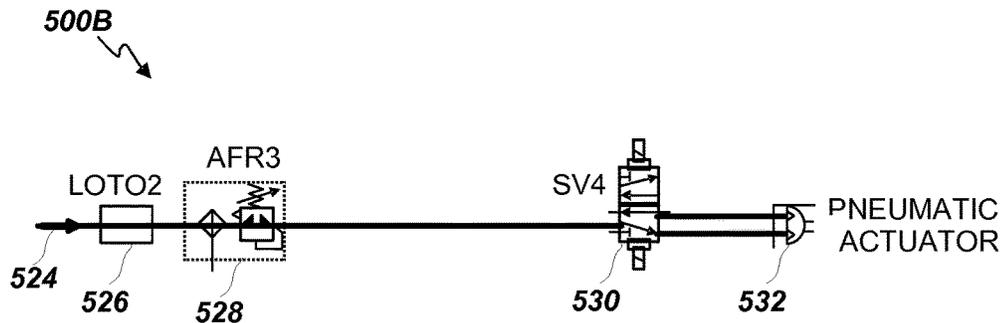


FIG. 5B

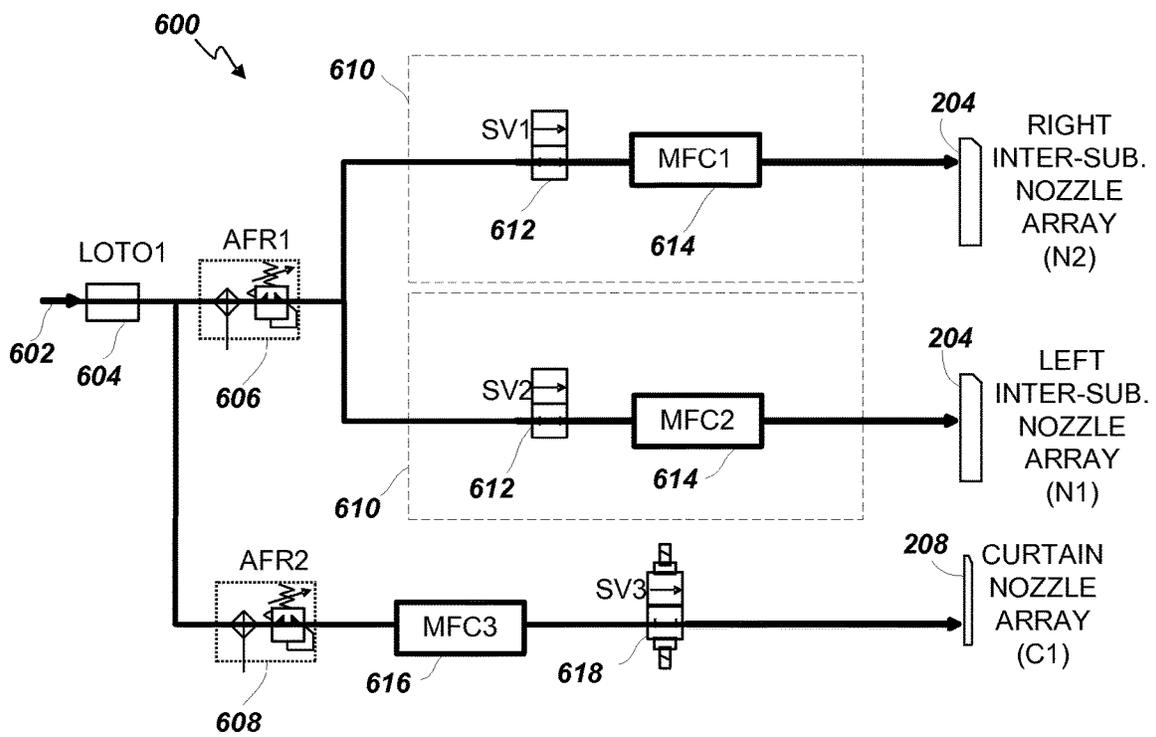


FIG. 6

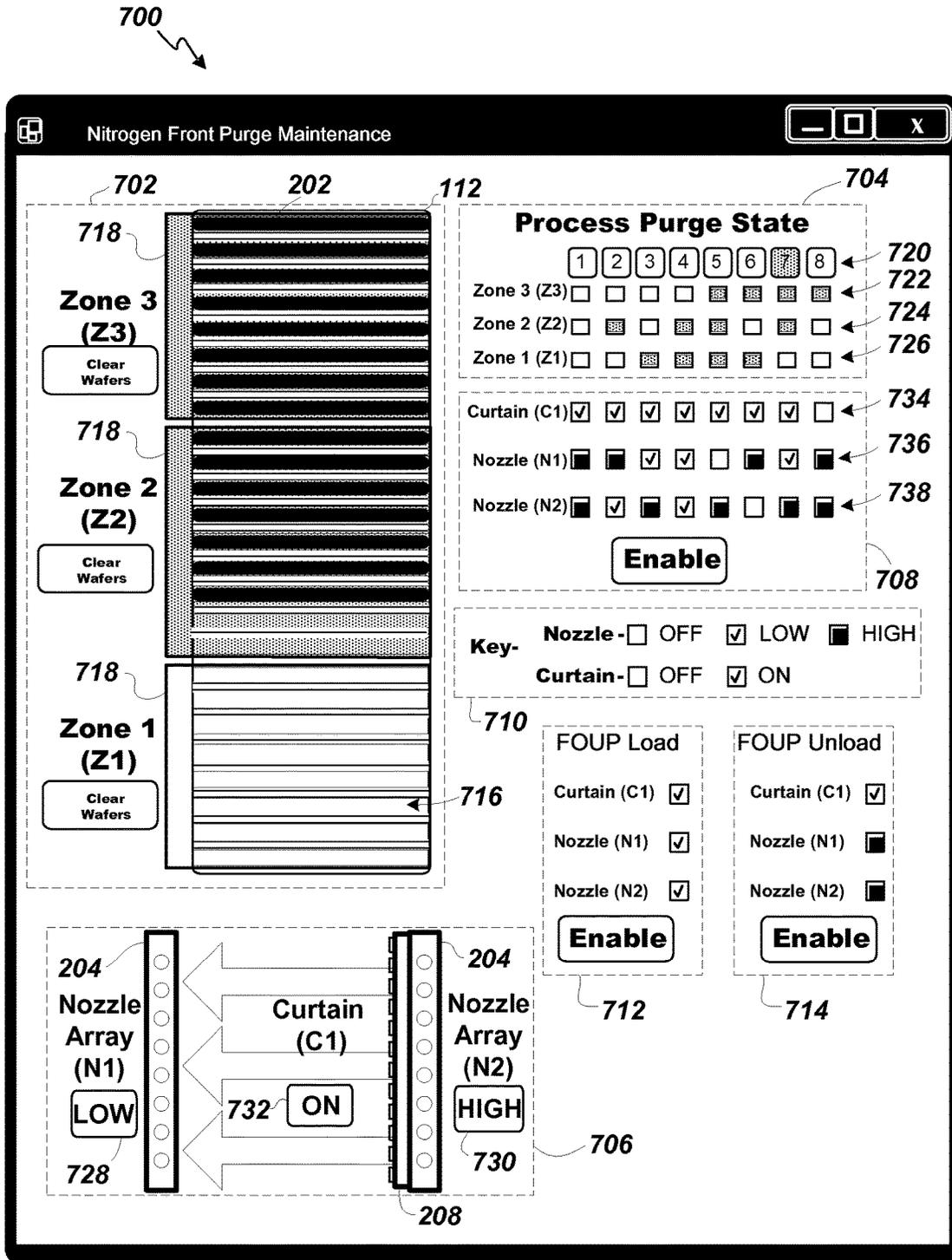


FIG. 7

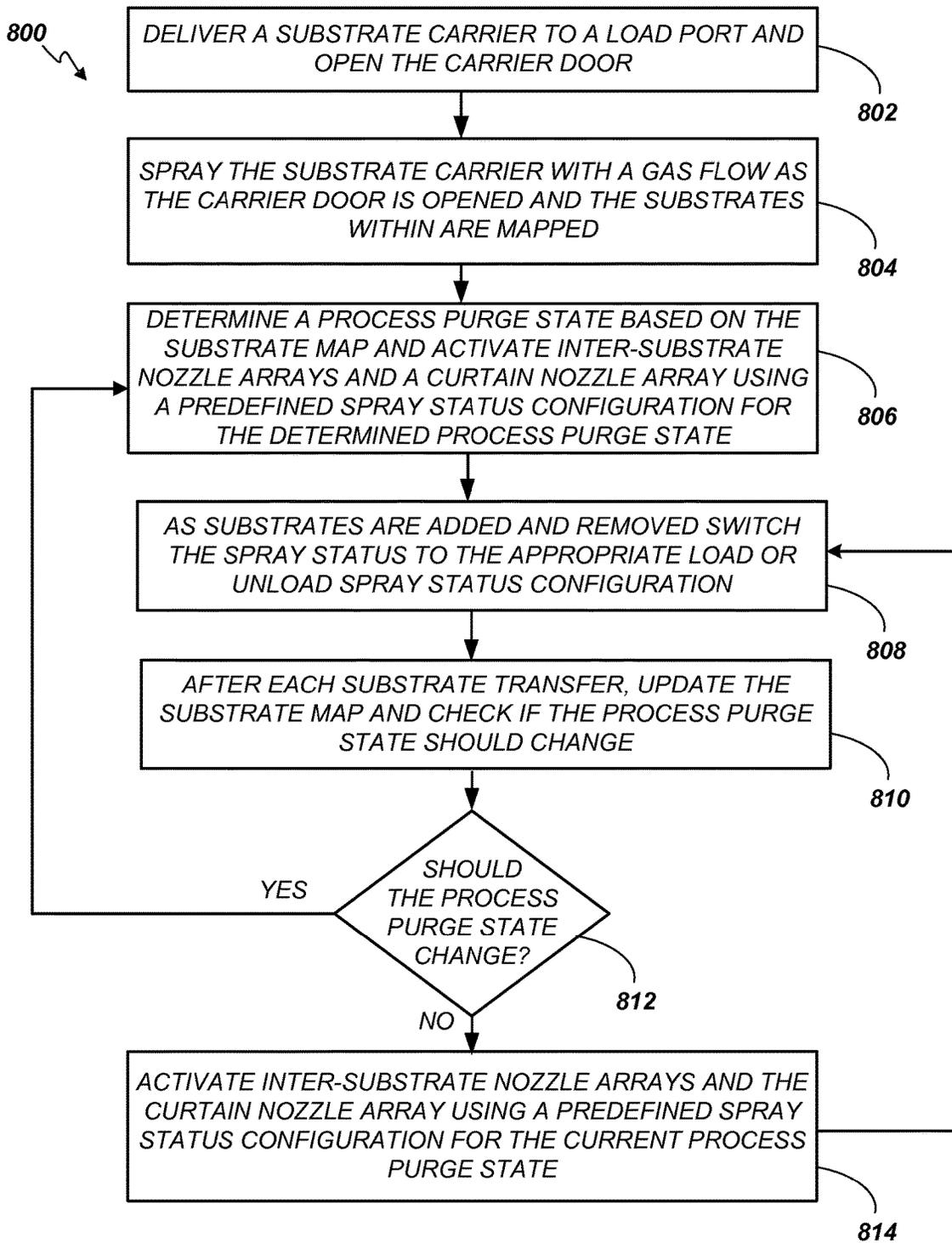


FIG. 8

# SYSTEMS, APPARATUS, AND METHODS FOR PURGING A SUBSTRATE CARRIER AT A FACTORY INTERFACE

## RELATED APPLICATIONS

This claims the benefit of U.S. Provisional Patent Application No. 62/068,617, filed Oct. 24, 2014, and titled "SYSTEMS, APPARATUS, AND METHODS FOR PURGING A SUBSTRATE CARRIER AT A FACTORY INTERFACE", which is hereby incorporated by reference herein in its entirety for all purposes.

## FIELD

The present invention relates to processing substrate carriers, and more specifically to systems, apparatus, and methods for purging a substrate carrier at a factory interface or equipment front end module.

## BACKGROUND

As the semiconductor manufacturing industry transitions to smaller and smaller technologies such as 22 nm, 14 nm, and so on, oxidation defects and particulate matter become a more critical problem to solve. Numerous studies conducted by manufacturers and other researchers have noted that maintaining an inert environment in the substrate carriers significantly reduces defects caused by moisture and oxidation. Existing solutions however require manufactures to replace the load ports and substrate carriers used in the electronic device manufacturing facilities. These components are expensive to replace and may not be compatible with other systems in the manufacturing facilities. Thus, what is needed are systems, methods and apparatus that allow manufacturers to maintain an inert environment in substrate carriers being processed at a factory interface that does not require new load ports or new substrate carriers.

## SUMMARY

In some embodiments, the present invention provides a kit for purging a substrate carrier at a factory interface (FI) or equipment front end module (EFEM). Embodiments of the kit include a frame configured to sit proximate to a load port door without interfering with operation of a FI or EFEM robot; one or more inter-substrate nozzle arrays supported by the frame and configured to spray gas into a substrate carrier; and one or more curtain nozzle arrays supported by the frame and configured to spray gas across an opening of the substrate carrier.

In some other embodiments, the present invention provides a system for purging a substrate carrier. The system includes a load port including a door and adapted to receive a substrate carrier; a frame configured to sit proximate to the load port door without interfering with operation of a FI or EFEM robot; one or more inter-substrate nozzle arrays supported by the frame and configured to spray gas into the substrate carrier; and one or more curtain nozzle arrays supported by the frame and configured to spray gas across an opening of the substrate carrier.

In yet other embodiments, the present invention provides a method for purging a substrate carrier. The method includes delivering a substrate carrier to a load port and opening a door of the carrier; spraying the substrate carrier with a gas flow as the carrier door is opened and substrates within the carrier are mapped; determining a process purge

state based on a substrate map; and activating one or more inter-substrate nozzle arrays and one or more curtain nozzle arrays using a predefined spray status configuration for the determined process purge state.

Still other features, aspects, and advantages of the present invention will become more fully apparent from the following detailed description, the appended claims, and the accompanying drawings by illustrating a number of exemplary embodiments and implementations, including the best mode contemplated for carrying out the present invention. Embodiments of the present invention may also be capable of other and different applications, and its several details may be modified in various respects, all without departing from the spirit and scope of the present invention. Accordingly, the drawings and descriptions are to be regarded as illustrative in nature, and not as restrictive. The drawings are not necessarily drawn to scale. The description is intended to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the claims.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram depicting an example substrate carrier purge system according to embodiments of the present invention.

FIG. 2 is a schematic diagram depicting an example gas spray pattern of a substrate carrier purge system according to embodiments of the present invention.

FIG. 3 is a schematic diagram depicting an example nozzle array of a substrate carrier purge system according to embodiments of the present invention.

FIGS. 4A and 4B are schematic front and side views of an example frame of a substrate carrier purge system according to embodiments of the present invention.

FIG. 5A is a schematic pneumatic circuit diagram depicting a first example gas flow control circuit of a substrate carrier purge system according to embodiments of the present invention.

FIG. 5B is a schematic pneumatic circuit diagram depicting a first example optional actuator circuit of a substrate carrier purge system according to embodiments of the present invention.

FIG. 6 is a schematic pneumatic circuit diagram depicting a second example gas flow control circuit of a substrate carrier purge system according to embodiments of the present invention.

FIG. 7 is a screenshot depicting an example of a control interface of a substrate carrier purge system according to embodiments of the present invention.

FIG. 8 is a flowchart illustrating an example method of purging a substrate carrier at a factory interface according to embodiments of the present invention.

## DETAILED DESCRIPTION

Embodiments of the present invention provide systems, apparatus, and methods for purging a substrate carrier at a factory interface. The systems and methods ensure that a substrate carrier environment (e.g., the inside of a front-opening unified pod (FOUP)) is purged with an inert gas such as nitrogen or argon to mitigate the effects of oxidation, moisture, and particle contamination, and to mitigate risks of other potential defect causing phenomenon such as out gassing wafers, etc. Embodiments of the present invention provide a field retrofit-able factory interface (FI)/equipment front end module (eFEM) kit that allows for purging of a substrate carrier with nitrogen (N<sub>2</sub>) or any other practicable

inert gas such as argon when the substrate carrier is being processed on a tool. A universal front purge FI/eFEM kit according to embodiments of the present invention can include two vertically disposed inter-substrate purge nozzle arrays (positioned on the sides of the FI/eFEM door opening) and one curtain nozzle array (positioned next to one of the inter-substrate purge nozzle arrays on the side of the FI/eFEM door opening). The combination of the gas flows from the nozzle arrays is controlled so as to achieve an optimum purge of the substrate carrier. The novel kit is configured to work with all substrate carriers and automatic door opener (ADO) configurations.

The kit is further configured to be mounted on the FI frame/panels/robot track or on the datum plate. The purging assembly (e.g., the nozzle arrays and frame) can be stationary or moveable based on performance requirements and space constraints. The FI/eFEM control system can be configured to be used to control the purging operation of the kit. Performance of the purging operation can be dependent on (e.g., gated by) the FI safety interlocks, load port status, and robot motion. The kit helps improve the associated tool's yield by providing an inert environment inside a substrate carrier and thereby reduces defects from particulate matter.

The universal compatibility of the kit with all ADO and substrate carrier types makes it a more commercially feasible option for upgrading FIs/eFEMs than replacement of substrate carriers and load ports. The FI controls can be configured to provide precise control over the timing and flow rate of the inert gas. These controls can be completely integrated into the FI control software and safety systems. In some embodiments, the flow of the gases can be adjusted dynamically and continuously in response to the number and position of substrates in the substrate carrier at any given time.

Turning now to FIG. 1, an example embodiment of substrate carrier purge system **100** for an FI is depicted. The system **100** includes a substrate carrier purge kit **102** that is adapted to be mounted on a FI robot track **104** and, in some embodiments, the FI frame **106**. The FI robot track **104** provides a rail, gantry, frame, or stage for precise lateral movement of the base of the FI robot **108** to allow the FI robot **108** to access the various load ports of the FI. In embodiments of the system **100** without an FI robot track **104** (e.g., a system **100** that includes an FI robot that can reach multiple load ports without having to have its base moved laterally), the substrate carrier purge kit **102** can be mounted to the FI frame **106**, FI panels and/or on a datum plate of the FI. As shown, the substrate carrier purge kit **102** is configured to direct multiple gas streams **110** or flows (represented as dashed arrows in FIG. 1) into a substrate carrier **112** loaded on a load port **114** of the FI when the door **116** has been opened. The system **100** operates under control of controller **118** which can be operatively coupled to the various components, including the substrate carrier purge kit **102**, via wired or wireless communications network(s).

FIG. 2 depicts a top view **200** of the system **100** that illustrates the expanding flow direction of the gas streams **110** (represented as dashed triangles in FIG. 2) toward substrates **202** in the carrier **112** in more detail. Inter-substrate nozzle arrays **204** within the substrate carrier purge kit **102** are aimed to flow gas over the major surfaces of the substrates **202**. In some embodiments, the inter-substrate nozzle arrays **204** are aimed at an angle of approximately 45 degrees relative to the sides of the substrate carrier **112** (as indicated by arrows **206**). In some embodiments the aiming angle of the inter-substrate nozzle arrays **204** (i.e., arrow

**206**) can be adjusted to aim the gas streams **110** at any desired direction (e.g., at the center point of the substrates **202**) or angle it from directly into the substrate carrier (zero degrees) to perpendicular to the substrate sides (90 degrees). In some embodiments, the inter-substrate nozzle arrays **204** can be configured to oscillate (e.g., sweep back and forth over a range of angles, for example, zero to 90 degrees) or the angle can be changed based on the number and/or location of substrates **202** currently in the carrier **112** and/or to achieve a desired gas flow pattern. The nozzles of the inter-substrate nozzle arrays **204** are adapted to cause the gas streams **110** to expand with an angle  $\theta$  of between approximately zero degrees and approximately 120 degrees. In some embodiments, the angle  $\theta$  can be changed over time based on the number and/or location of substrates **202** currently in the carrier **112** and/or to achieve a desired gas flow pattern. Thus, in some embodiments, adjustable and/or aim-able nozzles can be used in the inter-substrate nozzle arrays **204**.

FIG. 2 also depicts an example of a curtain nozzle array **208** disposed adjacent to one of the inter-substrate nozzle arrays **204**. In some embodiments, the curtain nozzle array **208** has the same general structure as the inter-substrate nozzle arrays **204** but can include nozzles configured to generate a narrower, continuous, even, and consistent plane of gas. The curtain nozzle array **208** is configured to direct a plane or sheet of gas laterally (e.g., approximately parallel to the opening of the substrate carrier **112**) across the opening of the substrate carrier **112** to form a gas curtain **210** aimed in the direction indicated by arrow **212** with an expansion angle  $\theta'$ . In some embodiments the aiming angle of the curtain nozzle array **208** (i.e., arrow **212**) can be adjusted to aim the gas curtain **210** in any desired direction (e.g., across the opening of the substrate carrier **112** (zero degrees)) or angle it from into the substrate carrier (-45 degrees) to away from the substrate carrier (+45 degrees). In some embodiments, the expansion angle  $\theta'$  of the gas curtain **210** flow can be between approximately zero degrees and approximately 120 degrees. The gas curtain **210** from the curtain nozzle array **208** effectively blocks any particles, moisture, or other gases that may be in the FI from entering the substrate carrier **112**. In some embodiments, the curtain nozzle array **208** can be aimed away from the substrate carrier **112** at a small angle (e.g., less than 15 degrees from the plane of the carrier opening) to draw gas away from the carrier **112** and create a lower pressure area in front of the carrier **112**, further reducing the chances of particles, moisture, or other gases that may be in the FI from entering the substrate carrier **112**.

In some embodiments, the curtain nozzle array **208** can be disposed horizontally relative to the inter-substrate nozzle arrays **204** and above the substrate carrier opening aimed downward. In other words, the curtain nozzle array **208** can be positioned across the top of the substrate carrier purge kit **102** to direct a sheet of gas down across the opening of the substrate carrier **112**. In yet other embodiments, the curtain nozzle array **208** can be positioned below the substrate carrier opening to direct a sheet of gas upward across the opening of the substrate carrier **112**.

In some embodiments, both the inter-substrate nozzle arrays **204** and the curtain nozzle array **208** can include adjustable nozzles that can be dynamically adjusted during operation to change nozzle exit velocity, spray angle, expansion angle, flow pattern, oscillation rate, nozzle shape and size, etc.

In some embodiments, the gas flow rates and gas flow patterns can be adjusted to optimally reduce particles, mois-

ture, or other gases from entering the carrier **112**. For example, to both maintain a slight positive pressure (e.g., approximately 0.005 ATM) in the carrier **112** relative to the air pressure in the FI and to create a laminar flowing, swirl pattern that moves air from the back of the carrier **112** out the center of the carrier opening, gas can be flowed into the carrier **112** from the inter-substrate nozzle arrays **204** at specified rates and angles. For example, in some embodiments using a standard 25-slot substrate carrier loaded with 25 substrates **202**, optimal results (e.g., minimized O<sub>2</sub> concentration within the carrier **112**) can be achieved by spraying N<sub>2</sub> into the carrier **112** at a 45 degree angle relative to the sides of the carrier **112** and at a rate of approximately 60 SLM from one side of the inter-substrate nozzle arrays **204** and approximately 30 SLM from the other side, while the curtain nozzle array **208** sprays gas at a rate of approximately 75 SLM.

Turning now to FIG. 3, a side view **300** of the system **100** that illustrates the flow direction of the gas streams **110** (represented as dashed triangles in FIG. 2 from the inter-substrate nozzle arrays **204** into the carrier **112** and between the substrates **202** in more detail. In some embodiments, the nozzle body **302** of the inter-substrate nozzle arrays **204** (and the curtain nozzle array **208**) is configured to hold a removable/replaceable nozzle head **304** that includes a plurality of nozzles **306**. The number of nozzles **306** can be a function of the size of the substrate carrier **112** being used. For example, a nozzle head **304** with 50 nozzles **306** can be used with a substrate carrier **112** configured to hold up to 25 substrates **202**. In this configuration, a pair of nozzles **306** can be disposed to spray gas at the top and bottom of each substrate **202**. For a substrate carrier **112** adapted to hold up to 13 substrates, a nozzle head **304** with 26 nozzles can be used.

When inserted into the nozzle body **302**, a plenum **308** within the nozzle head **304** becomes in fluid communication with a gas supply channel **310** via ports at either or both ends of the nozzle head **304**. In some embodiments, the number and arrangement of the nozzles **306** can be different in different nozzle heads **304** and thus, by replacing the nozzle head **304**, different configurations of nozzles can be achieved. In addition to the nozzles **306**, the shape of the plenum **308** can be different for different nozzle heads **304**. In some embodiments, the plenum **308** can include an adjustable bellows (not shown) that can change the shape of the plenum **308** (e.g., the relative distances between the back wall of the plenum **308** and the various nozzles **306**) to alter the relative pressure/amount of gas going to different nozzles **306**. The bellows can be controlled by system software running on the controller **118**.

In some embodiments, a nozzle orifice plate **312** is disposed in front of the nozzles **306** to provide control over individual nozzles. For example, the nozzle orifice plate **312** can include a plurality of sets of regularly spaced orifices of varying size and shape disposed to correspond with the number and position of the nozzles **306**. Thus, by moving the nozzle orifice plate **312** between different sets of orifices, various characteristics of the gas spray pattern can be adjusted. In some embodiments, the position of the nozzle orifice plate **312** is controlled by system software running on the controller **118**. The position of the nozzle orifice plate **312** can be indexed to a series of notches in the plate **312** that allow a sealed stepper motor (not shown) to both change and track the plate's position.

The removable nozzle head **304** allows interchange of different nozzles in the field to alter the gas flow characteristics such as nozzle exit velocity, spray angle, and direction

of the flow into the substrate carrier **112**. The same design philosophy is applied to the curtain nozzle array **208**. The curtain nozzle heads are also interchangeable to also allow interchange of different nozzles in the field to alter the flow characteristics such as nozzle exit velocity, spray angle, and direction of the flow across the substrate carrier opening. For example, a nozzle head for a curtain nozzle array **208** can include nozzles that are angled away from the substrate carrier opening to allow the purge gas (e.g., ionized or non-ionized) to dislodge any particles that may be on the incoming/outgoing substrate (or end effector) into an enclosed minienvironment in front of the carrier and thereby forced out of the FI by air flow towards an exhaust.

In some embodiments, instead of inter-substrate nozzle arrays **204**, or in place of one of the inter-substrate nozzle arrays **204**, a vacuum port array (not shown) can be provided. Likewise, instead of, or in addition to (e.g., disposed across the carrier opening), a curtain nozzle array, a vacuum port array can be provided. A vacuum port array can include multiple suction ports or an elongated slot that serves as a suction port. Even when using a vacuum port array, it can be desirable to maintain a positive pressure within the substrate carrier by ensuring that gas enters the carrier at a higher rate than it exits.

In some embodiments, each of the four edges of the substrate carrier can be configured to include one or more of an inter-substrate nozzle array, a curtain nozzle array, and/or a vacuum nozzle array positioned in any practicable arrangement. Thus, the arrangement of inter-substrate nozzle arrays, curtain nozzle arrays, and/or vacuum nozzle arrays can be entirely configurable and is not restricted to just two vertical inter-substrate nozzle arrays and a single vertical or horizontal curtain nozzle array.

FIGS. 4A and 4B indicate frame dimensions of the substrate carrier purge kit **102** that allow the kit **102** to be universally compatible with ADOs, load ports **114**, and substrate carriers **112** compliant with the Semiconductor Equipment and Materials International (SEMI®) trade association's E62 standard. FIG. 4A depicts a front view **400A** of the frame of the kit **102**. The overall outer dimension A is in the range of approximately 400 mm to approximately 440 mm; the inner dimension B is in the range of approximately 360 mm to approximately 400 mm; and the nozzle array height dimension C corresponding to the carrier door opening is in the range of approximately 250 mm to approximately 300 mm. FIG. 4B depicts a side view **400B** of the frame of the kit **102**. The overall depth dimension D of the kit **102** is less than approximately 100 mm. The SEMI E62 standard is for 300 mm substrates. Other dimensions practicable for different standards can be used. For example, the SEMI E154 standard defines dimensions for 450 mm substrates and a substrate carrier purge kit **102** can be configured to work with devices compliant with the E154 standard. In other words, the kit **102** of embodiments of the current invention can be configured to be compatible with all SEMI compliant load ports, ADOs and substrate carriers.

Turning now to FIG. 5A, a schematic diagram depicting an example of a gas flow control pneumatic circuit **500A** for a substrate carrier purge system **100** is shown. A pressurized inert gas supply **502** (e.g., nitrogen, argon, etc.) is coupled to a supply valve **504** (e.g., a lock-out tag-out (LOTO valve)) whose output is coupled to a first air filter regulator **506** (AFR1) for the inter-substrate nozzle arrays **204** and a second air filter regulator **508** (AFR2) for the curtain nozzle array **208**. The first air filter regulator **506** and the second air filter regulator **508** control the proportion of source gas

pressure delivered to the inter-substrate nozzle arrays **204** versus the curtain nozzle array **208**.

The flow from the first air filter regulator **506** is split between two parallel sub-circuits **510** for the two inter-substrate nozzle arrays **204**. The two sub-circuits **510** can each include the same components. For example, the sub-circuits can each include a valve **512** (e.g., a solenoid valve) for turning the respective inter-substrate nozzle array **204** on or off. Coupled to the output of the valve **512**, the sub-circuits **510** each also include two flow switches **514** in parallel with each other and each flow switch **514** is coupled in series with a different flow restrictor **516** that are each settable to allow different flow rates. Coupled to the outputs of the flow restrictors **516**, the sub-circuits **510** each also include a shuttle valve **518** that allows selection between flows from the two different flow switches **514**. Thus, each of the sub-circuits **510** allows selection between three different flow states: (1) off, (2) a first flow rate (e.g., "high"), and (3) a second flow rate (e.g., "low"). The output of the sub-circuits **510** are coupled to the gas supply channel **310** of the respective inter-substrate nozzle array **204**. For example, in some embodiments, one sub-circuit **510** is coupled to the inter-substrate nozzle array **204** on the right-hand side of the substrate carrier purge kit **102** and the other sub-circuit **510** is coupled to the inter-substrate nozzle array **204** on the left-hand side.

The flow from the second air filter regulator **508** is fed to a flow switch **520** in series with a flow restrictor **521** together used to set the flow rate of the gas to the curtain nozzle array **208**. The output of the flow restrictor **521** is coupled to the input of a valve **522** (e.g., a solenoid valve) for turning the curtain nozzle array **208** on or off. The output of the valve **522** is coupled to the input of the curtain nozzle array **208**.

In embodiments where the angle of the inter-substrate nozzle arrays **204** and/or the curtain nozzle array **208** are adjustable or dynamically adjustable (e.g., adjustable in use and/or while spraying gas) or where the arrays are adapted to oscillate, one or more pneumatic actuator circuits **500B** as depicted in FIG. 5B can be used to move the arrays. The example pneumatic actuator circuit **500B** shown includes a clean dry air (CDA) supply **524** coupled to a supply valve **526** (e.g., a LOTO valve) whose output is coupled to a third air filter regulator **528** (AFR3). The output of the third air filter regulator **528** is fed to the input of a valve **530** (e.g., a solenoid valve) for controlling operation of a pneumatic actuator **532** (e.g., a linear or rotatory actuator). In some embodiments, one or more pneumatic actuator circuits **500B** can be used to drive motion of the inter-substrate nozzle arrays **204**, the curtain nozzle array **208**, an adjustable bellows in the plenum **308** of the nozzle head **304**, a nozzle orifice plate **312** (FIG. 3) on the inter-substrate nozzle arrays **204** or the curtain nozzle array **208**, and/or any other moveable or adjustable mechanical assemblies.

FIG. 6 depicts a second example of a gas flow control pneumatic circuit **600** for a substrate carrier purge system **100**. A pressurized inert gas supply **602** (e.g., nitrogen, argon, etc.) is coupled to a supply valve **604** (e.g., a LOTO valve) whose output is coupled to a first air filter regulator **606** (AFR1) for the inter-substrate nozzle arrays **204** and a second air filter regulator **608** (AFR2) for the curtain nozzle array **208**. The first air filter regulator **606** and the second air filter regulator **608** control the proportion of source gas pressure delivered to the inter-substrate nozzle arrays **204** versus the curtain nozzle array **208**.

The flow from the first air filter regulator **606** is split between two parallel sub-circuits **610** for the two inter-substrate nozzle arrays **204** (e.g., positioned on the left and

right hand sides of the substrate carrier opening). The two sub-circuits **610** can each include the same components. For example, the sub-circuits can each include a valve **612** (e.g., a solenoid valve) for turning the respective inter-substrate nozzle array **204** on or off. Coupled to the output of the valve **612**, the sub-circuits **610** can each also include a mass flow controller **614**, each one coupled to one of the two inter-substrate nozzle arrays **204**. Thus, the sub-circuits **610** allow selection between being off and any desired flow rate up to the maximum flow rate provided by the first air filter regulator **606**. The output of the sub-circuits **610** are coupled to the gas supply channel **310** (FIG. 3) of the respective inter-substrate nozzle array **204**. For example, in some embodiments, one sub-circuit **610** is coupled to the inter-substrate nozzle array **204** on the right-hand side of the substrate carrier purge kit **102** and the other sub-circuit **610** is coupled to the inter-substrate nozzle array **204** on the left-hand side.

The flow from the second air filter regulator **608** is fed to a mass flow controller **616** used to set the flow rate of the gas to the curtain nozzle array **208**. The output of the mass flow controller **616** is coupled to the input of a valve **618** (e.g., a solenoid valve) for turning the curtain nozzle array **208** on or off. The output of the valve **618** is coupled to the input of the curtain nozzle array **208**.

As with the gas flow control pneumatic circuit **500A** of FIG. 5, the gas flow control pneumatic circuit **600** of FIG. 6 can also optionally include one or more pneumatic actuator circuits **500B** as depicted in FIG. 5B for controlling operation of a pneumatic actuator **532** (e.g., a linear or rotatory actuator). As indicated above, in some embodiments, one or more pneumatic actuator circuits **500B** can be used to drive motion of the inter-substrate nozzle arrays **204**, the curtain nozzle array **208**, an adjustable bellows in the plenum **308** of the nozzle head **304** (FIG. 3), a nozzle orifice plate **312** (FIG. 3) on the inter-substrate nozzle arrays **204** or the curtain nozzle array **208**, and/or any other moveable or adjustable mechanical assemblies.

Turning now to FIG. 7, a screenshot window of an example control interface **700** for a substrate carrier purge system **100** is depicted. Although many different control interfaces can be used, the following example interface is described in detail to illustrate operational features of the system **100**. The control interface **700** can include several display/control areas that provide process status and/or configuration controls. The example display/control areas shown in FIG. 7 are each enclosed in a separate dashed line rectangle. For example, the example control interface **700** includes a substrate carrier status area **702**, a process purge state display area **704**, a nozzle array status area **706**, a nozzle array configuration control area **708**, a key display area **710**, a carrier load nozzle array control area **712**, and a carrier unload nozzle array control area **714**. Additional or fewer display/control areas can be used.

The substrate carrier status area **702** includes a representation of a substrate carrier **112** that includes a number of substrate slots **716** grouped into logical zones **718**. Each slot can hold one substrate **202** and the number of slots per zone and the number of zones per carrier can be configured by a user. For example, in the particular configuration depicted in FIG. 7, the carrier **112** includes three zones **718**, Zone 1 which is empty of substrates **202**, includes 8 slots **716**, Zone 2 which has seven substrates **202**, includes 9 slots **716** (two are empty), and Zone 3 which is full of substrates **202**, includes eight slots **716**. Note that the representation of the

substrate carrier **112** can be modified to reflect any size carrier (with the appropriate number of slots) used with the system **100**.

In another example, each zone **718** can include only one slot **716** and the carrier **112** can have 25 zones **718**. In yet another example, a carrier **112** can have only one zone **718**. Once the substrate carrier **112** is mapped, the substrates **202** present in the carrier **112** can be represented in the substrate carrier status area **702**. Each time a substrate **202** is removed from the carrier **112** for processing or returned to the carrier **112** from processing, the substrate carrier status area **702** is updated. Thus, the substrate carrier status area **702** serves as a current map of the substrates **202** in the carrier **112**.

In operation, each Zone **718** is checked for at least one substrate **202** being present. If a substrate **202** is present then the zone status will be set to TRUE. If no substrates **202** are present then respective zone status will be set FALSE. This is done for each respective Zone **718**. In the particular example shown, there can be a combination of eight process purge states **704** possible from the three Zones **718**. Each additional zone **718** would increase the number of possible process purge state **704** combinations based on the following formula:  $n=2^y$  where  $n$  represents the number of possible process purge states and  $y$  represents the number of zones. Thus two zones **718** would have four process purge state **704** combinations, three zones **718** have eight process purge state **704** combinations, four zones **718** would have sixteen process purge state **704** combinations, twenty-five zones **718** would yield 33,554,432 process purge state **704** combinations, etc. A "Clear Wafers" button provided for each zone **718** allows an operator to test various zone configurations in a simulation mode.

The process purge state display area **704** reflects the current purge state of the system **100** and is determined based upon which zones **718** currently have at least one substrate **202** in them. As shown in Row **720** of the process purge state display area **704**, State 7 is highlighted indicating that the current process purge state is State 7. This is the case because Zone 1 is empty of substrates while Zones 2 and 3 each have at least one substrate present (note that Zones 2 and 3 are highlighted while Zone 1 is not). Row **722**, Row **724** and Row **726** together provide a truth table-like representation of all the possible process purge states 1 through 8. Review of the table reveals that State 7 corresponds to the current status of the zones **718** in the carrier **112**. In an illustrative example, if one substrate was to be returned to a slot **716** in Zone 1 of the carrier **112**, the process purge state would change to State 5 (i.e., all zones include at least one substrate). If then all the substrates in Zones 2 and 3 were removed, leaving one substrate in Zone 1, the process purge state would change to State 3.

The nozzle array status area **706** indicates the current status of the inter-substrate nozzle arrays **204** and the curtain nozzle array **208**. The status of the arrays is determined based upon the configuration defined in the nozzle array configuration control area **708** (described below) based upon the current process purge state indicated in the process purge state display area **704**. In this example configuration (e.g., FIG. 5A), the inter-substrate nozzle arrays **204** are tri-state meaning they can be off, low, or high and the curtain nozzle array **208** is bi-state meaning it is either on or off. The current state of the inter-substrate nozzle array **204** on the left (N1) is indicated by the status indicia **728**, the current state of the inter-substrate nozzle array **204** on the right (N2) is indicated by the status indicia **730**, and the current state of the curtain nozzle array **208** in the center (C1) is indicated by the status indicia **732**. To illustrate the example shown,

currently while the system **100** in in process purge State 7 as indicated in the process purge state display area **704**, Row **720**, N1 is LOW, N2 is HIGH, and C1 is ON.

The current status of the arrays indicated in the nozzle array status area **706** is dictated by the nozzle array configuration control area **708** and the current process purge state. The nozzle array configuration control area **708** includes a curtain nozzle array row **734** that defines the desired state for each process purge state, a left inter-substrate nozzle array (N1) row **736** that defines the desired state for each process purge state, and a right inter-substrate nozzle array (N2) row **738** that defines the desired state for each process purge state. Each input box on each row allows selection of the desired status for the particular row's array for each process purge state (i.e., each column).

The various statuses available for each type of array are indicated in the key display area **710** and correspond to the hardware configuration of the gas flow control pneumatic circuit **500A** (FIG. 5). As shown, inter-substrate nozzle arrays can be configured to be OFF (indicated by an empty input box), LOW (indicated by a checked input box), and HIGH (indicated by a filled input box). Curtain nozzle arrays can be configured to be OFF (indicated by an empty input box) and ON (indicated by a checked input box). Alternative symbols and arrangements can be used.

In addition to the eight process purge states defined in the process purge state display area **704** based on the absence or presence of at least one substrate in each zone, two additional purge states can be defined based upon the presence of an end effector of the FI robot in the substrate carrier. During a substrate carrier load operation, an end effector with a substrate enters the carrier, places the substrate into a slot, and then the empty end effector withdraws. During a substrate carrier unload operation, an empty end effector enters the carrier, picks up a substrate from a slot, and then the end effector holding the substrate withdraws from the carrier.

The carrier load nozzle array control area **712** defines the configuration status of the curtain nozzle array **208** and the inter-substrate nozzle arrays **204** during the substrate carrier load process. The carrier unload nozzle array control area **714** defines the configuration status of the curtain nozzle array **208** and the inter-substrate nozzle arrays **204** during the substrate carrier unload process. In both the carrier load nozzle array control area **712** and the carrier unload nozzle array control area **714**, the same symbols used in the key display area **710** can be used.

An additional configuration control that can be included in both the carrier load nozzle array control area **712** and the carrier unload nozzle array control area **714** is an end effector-type indicator. For example, in some embodiments, end effectors that include a clamping mechanism for securely holding a substrate can be used. In other embodiments, end effectors that do not clamp the substrates can be used. If the substrate is not secured to the end effector with a clamping mechanism, a user may not want to risk having the substrate dislodged from the end effector by a gas flow from one or more of the arrays. Thus, an end effector-type indicator can be used to override the configuration in the carrier load nozzle array control area **712** or in the carrier unload nozzle array control area **714** if a non-clamping end effector blade is used.

In some embodiments, an additional display/control area can be provided to control operation of the pneumatic actuator circuits **500B** (FIG. 5B) to control additional configuration options such as motion of the inter-substrate nozzle arrays **204**, the curtain nozzle array **208**, an adjust-

able bellows in the plenum **308** of the nozzle head **304**, a nozzle orifice plate **312** (FIG. 3) on the inter-substrate nozzle arrays **204** or the curtain nozzle array **208**, and/or any other moveable or adjustable mechanical assemblies.

In embodiments where the gas flow control pneumatic circuit **600** with mass flow controllers **614** is used, instead of simple tri- or bi-state status input options, parameter values that specify actual flow rates can be entered into the input boxes of the curtain nozzle array row **734**, the left inter-substrate nozzle array (N1) row **736**, and the right inter-substrate nozzle array (N2) row **738** of the nozzle array configuration control area **708**. The gas flow control pneumatic circuit **600** can be controlled in response to the entered parameter values. Likewise, the input boxes in the carrier load nozzle array control area **712** and the carrier unload nozzle array control area **714** can be adapted to receive parameter values that specify actual flow rates to control the gas flows from the nozzle arrays. In some embodiments, alternative gases can be selected using an additional control input in the nozzle array configuration control area **708**.

Turning now to FIG. 8, a flow chart depicting an example method **800** of operating a substrate carrier purge system **100** according to embodiments of the present invention is provided. A substrate carrier is placed on a load port and the carrier door is opened (**802**). In some embodiments, a carrier door opening and mapping state can be defined wherein nozzle arrays spray a gas flow at the carrier as the carrier door is opened and the substrates within are mapped (**804**). Once the door is opened, the substrates within the carrier are mapped to determine or confirm the number and location of substrates actually in the carrier. Once the substrates are mapped, the system **100** determines the process purge state based on the substrate map and activates the inter-substrate nozzle arrays and the curtain nozzle array based upon the predefined configuration for the determined process purge state (**806**).

As substrates **202** are moved out of and into the substrate carrier **112** by the FI robot, the system **100** changes to the appropriate pre-defined spray status configuration specified in either the carrier load nozzle array control area **712** or the carrier unload nozzle array control area **714** (**808**). After each pick or place, the map is updated (**810**) and the system **100** determines if the process purge state should be changed (**812**). If so, a new process purge state is determined and the statuses of the nozzle arrays are changed according to the new state (**806**). If not, the nozzle arrays flow the gas according to the current process purge state (**814**).

The method repeats until all substrates have been processed and/or the substrate carrier is to be sealed and removed. In some embodiments, a carrier door closing state can be defined wherein nozzle arrays spray a gas flow at the carrier as the carrier door is closed.

Numerous embodiments are described in this disclosure, and are presented for illustrative purposes only. The described embodiments are not, and are not intended to be, limiting in any sense. The presently disclosed inventive concepts are widely applicable to numerous embodiments, as is readily apparent from the disclosure. One of ordinary skill in the art will recognize that the disclosed embodiments may be practiced with various modifications and alterations, such as structural, logical, software, and electrical modifications. Although particular features of the disclosed embodiments of the inventions may be described with reference to one or more particular embodiments and/or drawings, it should be understood that such features are not limited to usage in the one or more particular embodiments

or drawings with reference to which they are described, unless expressly specified otherwise.

The present disclosure is neither a literal description of all embodiments nor a listing of features of embodiments of the invention that must be present in all embodiments.

The Title (set forth at the beginning of the first page of this disclosure) is not to be taken as limiting in any way as the scope of the disclosed invention(s).

The term "product" means any machine, manufacture and/or composition of matter as contemplated by 35 U.S.C. § 101, unless expressly specified otherwise.

When a single device, component or article is described herein, more than one device, component or article (whether or not they cooperate) may alternatively be used in place of the single device, component or article that is described. Accordingly, the functionality that is described as being possessed by a device may alternatively be possessed by more than one device, component or article (whether or not they cooperate).

Similarly, where more than one device, component or article is described herein (whether or not they cooperate), a single device, component or article may alternatively be used in place of the more than one device, component or article that is described. For example, a plurality of computer-based devices may be substituted with a single computer-based device. Accordingly, the various functionality that is described as being possessed by more than one device, component or article may alternatively be possessed by a single device, component or article.

The functionality and/or the features of a single device that is described may be alternatively embodied by one or more other devices that are described but are not explicitly described as having such functionality and/or features. Thus, other embodiments need not include the described device itself, but rather can include the one or more other devices which would, in those other embodiments, have such functionality/features.

Devices that are in communication with each other need not be in continuous communication with each other, unless expressly specified otherwise. On the contrary, such devices need only transmit to each other as necessary or desirable, and may actually refrain from exchanging data most of the time. For example, a machine in communication with another machine via the Internet may not transmit data to the other machine for weeks at a time. In addition, devices that are in communication with each other may communicate directly or indirectly through one or more intermediaries.

A description of an embodiment with several components or features does not imply that all or even any of such components and/or features are required. On the contrary, a variety of optional components are described to illustrate the wide variety of possible embodiments of the present invention(s). Unless otherwise specified explicitly, no component and/or feature is essential or required.

Further, although process steps, algorithms or the like may be described in a sequential order, such processes may be configured to work in different orders. In other words, any sequence or order of steps that may be explicitly described does not necessarily indicate a requirement that the steps be performed in that order. The steps of processes described herein may be performed in any order practical. Further, some steps may be performed simultaneously or concurrently despite being described or implied as occurring non-simultaneously (e.g., because one step is described after the other step). Moreover, the illustration of a process by its depiction in a drawing does not imply that the illustrated process is exclusive of other variations and modifications

thereto, does not imply that the illustrated process or any of its steps are necessary to the invention, and does not imply that the illustrated process is preferred.

“Determining” something can be performed in a variety of manners and therefore the term “determining” (and like terms) includes calculating, computing, deriving, looking up (e.g., in a table, database or data structure), ascertaining, recognizing, and the like.

A “display” as that term is used herein is an area that conveys information to a viewer. The information may be dynamic, in which case, an LCD, LED, CRT, Digital Light Processing (DLP), rear projection, front projection, or the like may be used to form the display. The aspect ratio of the display may be 4:3, 16:9, or the like. Furthermore, the resolution of the display may be any appropriate resolution such as 480i, 480p, 720p, 1080i, 1080p or the like. The format of information sent to the display may be any appropriate format such as Standard Definition Television (SDTV), Enhanced Definition TV (EDTV), High Definition TV (HDTV), or the like. The information may likewise be static, in which case, painted glass may be used to form the display. Note that static information may be presented on a display capable of displaying dynamic information if desired. Some displays may be interactive and may include touch screen features or associated keypads as is well understood.

The present disclosure may refer to a “control system,” interface, or program. A control system, interface, or program, as that term is used herein, may be a computer processor coupled with an operating system, device drivers, and appropriate programs (collectively “software”) with instructions to provide the functionality described for the control system. The software is stored in an associated memory device (sometimes referred to as a computer readable medium). While it is contemplated that an appropriately programmed general purpose computer or computing device may be used, it is also contemplated that hard-wired circuitry or custom hardware (e.g., an application specific integrated circuit (ASIC)) may be used in place of, or in combination with, software instructions for implementation of the processes of various embodiments. Thus, embodiments are not limited to any specific combination of hardware and software.

A “processor” means any one or more microprocessors, Central Processing Unit (CPU) devices, computing devices, microcontrollers, digital signal processors, or like devices. Exemplary processors are the INTEL PENTIUM or AMD ATHLON processors.

The term “computer-readable medium” refers to any statutory medium that participates in providing data (e.g., instructions) that may be read by a computer, a processor or a like device. Such a medium may take many forms, including but not limited to non-volatile media, volatile media, and specific statutory types of transmission media. Non-volatile media include, for example, optical or magnetic disks and other persistent memory. Volatile media include DRAM, which typically constitutes the main memory. Statutory types of transmission media include coaxial cables, copper wire and fiber optics, including the wires that comprise a system bus coupled to the processor. Common forms of computer-readable media include, for example, a floppy disk, a flexible disk, hard disk, magnetic tape, any other magnetic medium, a CD-ROM, Digital Video Disc (DVD), any other optical medium, punch cards, paper tape, any other physical medium with patterns of holes, a RAM, a PROM, an EPROM, a FLASH-EEPROM, a USB memory stick, a dongle, any other memory chip or

cartridge, a carrier wave, or any other medium from which a computer can read. The terms “computer-readable memory” and/or “tangible media” specifically exclude signals, waves, and wave forms or other intangible or non-transitory media that may nevertheless be readable by a computer.

Various forms of computer readable media may be involved in carrying sequences of instructions to a processor. For example, sequences of instruction (i) may be delivered from RAM to a processor, (ii) may be carried over a wireless transmission medium, and/or (iii) may be formatted according to numerous formats, standards or protocols. For a more exhaustive list of protocols, the term “network” is defined below and includes many exemplary protocols that are also applicable here.

It will be readily apparent that the various methods and algorithms described herein may be implemented by a control system and/or the instructions of the software may be designed to carry out the processes of the present invention.

Where databases are described, it will be understood by one of ordinary skill in the art that (i) alternative database structures to those described may be readily employed, and (ii) other memory structures besides databases may be readily employed. Any illustrations or descriptions of any sample databases presented herein are illustrative arrangements for stored representations of information. Any number of other arrangements may be employed besides those suggested by, e.g., tables illustrated in drawings or elsewhere. Similarly, any illustrated entries of the databases represent exemplary information only; one of ordinary skill in the art will understand that the number and content of the entries can be different from those described herein. Further, despite any depiction of the databases as tables, other formats (including relational databases, object-based models, hierarchical electronic file structures, and/or distributed databases) could be used to store and manipulate the data types described herein. Likewise, object methods or behaviors of a database can be used to implement various processes, such as those described herein. In addition, the databases may, in a known manner, be stored locally or remotely from a device that accesses data in such a database. Furthermore, while unified databases may be contemplated, it is also possible that the databases may be distributed and/or duplicated amongst a variety of devices.

As used herein a “network” is an environment wherein one or more computing devices may communicate with one another. Such devices may communicate directly or indirectly, via a wired or wireless medium such as the Internet, LAN, WAN or Ethernet (or IEEE 802.3), Token Ring, or via any appropriate communications means or combination of communications means. Exemplary protocols include but are not limited to: Bluetooth™, Time Division Multiple Access (TDMA), Code Division Multiple Access (CDMA), Global System for Mobile communications (GSM), Enhanced Data rates for GSM Evolution (EDGE), General Packet Radio Service (GPRS), Wideband CDMA (WCDMA), Advanced Mobile Phone System (AMPS), Digital AMPS (D-AMPS), IEEE 802.11 (WI-FI), IEEE 802.3, SAP, the best of breed (BOB), system to system (S2S), or the like. Note that if video signals or large files are being sent over the network, a broadband network may be used to alleviate delays associated with the transfer of such large files, however, such is not strictly required. Each of the devices is adapted to communicate on such a communication means. Any number and type of machines may be in communication via the network. Where the network is the

Internet, communications over the Internet may be through a website maintained by a computer on a remote server or over an online data network including commercial online service providers, bulletin board systems, and the like. In yet other embodiments, the devices may communicate with one another over RF, cable TV, satellite links, and the like. Where appropriate encryption or other security measures such as logins and passwords may be provided to protect proprietary or confidential information.

It will be readily apparent that the various methods and algorithms described herein may be implemented by, e.g., appropriately programmed general purpose computers and computing devices. Typically a processor (e.g., one or more microprocessors) will receive instructions from a memory or like device, and execute those instructions, thereby performing one or more processes defined by those instructions. Further, programs that implement such methods and algorithms may be stored and transmitted using a variety of media (e.g., computer readable media) in a number of manners. In some embodiments, hard-wired circuitry or custom hardware may be used in place of, or in combination with, software instructions for implementation of the processes of various embodiments. Thus, embodiments are not limited to any specific combination of hardware and software. Accordingly, a description of a process likewise describes at least one apparatus for performing the process, and likewise describes at least one computer-readable medium and/or memory for performing the process. The apparatus that performs the process can include components and devices (e.g., a processor, input and output devices) appropriate to perform the process. A computer-readable medium can store program elements appropriate to perform the method.

The present disclosure provides, to one of ordinary skill in the art, an enabling description of several embodiments and/or inventions. Some of these embodiments and/or inventions may not be claimed in the present application, but may nevertheless be claimed in one or more continuing applications that claim the benefit of priority of the present application.

The foregoing description discloses only example embodiments of the invention. Modifications of the above-disclosed apparatus, systems and methods which fall within the scope of the invention will be readily apparent to those of ordinary skill in the art.

Accordingly, while the present invention has been disclosed in connection with exemplary embodiments thereof, it should be understood that other embodiments may fall within the spirit and scope of the invention, as defined by the following claims.

The invention claimed is:

1. A kit for purging a substrate carrier at a load port of a factory interface (FI) or equipment front end module (EFEM), the kit comprising:
  - a frame configured to sit proximate to a load port door without interfering with operation of the FI or an EFEM robot;
  - one or more inter-substrate nozzle arrays supported by the frame and configured to spray gas into a substrate

carrier, wherein the one or more inter-substrate nozzle arrays have an adjustable aiming angle; and one or more curtain nozzle arrays supported by the frame and configured to spray gas across an opening of the substrate carrier.

2. The kit of claim 1, wherein the kit is configured to be added to existing factory interfaces or equipment front end modules.

3. The kit of claim 1, wherein the one or more inter-substrate nozzle arrays includes two inter-substrate nozzle arrays each disposed vertically on a side of the opening of the substrate carrier.

4. The kit of claim 1, wherein the one or more curtain nozzle arrays include one curtain nozzle array disposed vertically on a side of the opening of the substrate carrier.

5. The kit of claim 1, wherein the one or more curtain nozzle arrays include one curtain nozzle array disposed horizontally on a top or bottom side of the opening of the substrate carrier.

6. The kit of claim 5, wherein the curtain nozzle array is configured to spray gas vertically across the opening of the substrate carrier.

7. The kit of claim 1, wherein the one or more inter-substrate nozzle arrays each includes two nozzles for each slot within the substrate carrier.

8. A system for purging a substrate carrier, the system comprising:

- a load port including a door and adapted to receive a substrate carrier;

- a frame configured to sit proximate to the door of the load port without interfering with operation of a factory interface (FI) or equipment front end module (EFEM) robot;

- one or more inter-substrate nozzle arrays supported by the frame and configured to spray gas into the substrate carrier, wherein the one or more inter-substrate nozzle arrays have an adjustable aiming angle; and

- one or more curtain nozzle arrays supported by the frame and configured to spray gas across an opening of the substrate carrier.

9. The system of claim 8, wherein the one or more inter-substrate nozzle arrays includes two inter-substrate nozzle arrays each disposed vertically on a side of the opening of the substrate carrier.

10. The system of claim 8, wherein the one or more curtain nozzle arrays include one curtain nozzle array disposed vertically on a side of the opening of the substrate carrier.

11. The system of claim 8, wherein the one or more curtain nozzle arrays include one curtain nozzle array disposed horizontally on a top or bottom side of the opening of the substrate carrier.

12. The system of claim 11, wherein the curtain nozzle array is configured to spray gas vertically across the opening of the substrate carrier.

13. The system of claim 8, wherein the one or more inter-substrate nozzle arrays each includes two nozzles for each slot within the substrate carrier.

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